

Introduction to TBU Protection



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1 BACKGROUND

1.1 THE SURGE THREAT

Surge protection is the process of protecting electronic systems or equipment from voltages and current which are outside their safe operating limits. These surge voltages and currents can be generated by short circuits, lightning or faults from a power system and usually enter the electronic system along inter-equipment wiring. The surges may be galvanically coupled into the system as in the case of a direct lightning strike, or through an inadvertent connection of the power system to the wiring, or as a result of an earth potential rise. They may be capacitively coupled into the system which may occur when a data system is used in the vicinity of a high voltage power line. They may be inductively coupled into the system as may occur if the wiring is run in parallel with large currents running in a power circuit feeding a high power motor.

The size and waveform of the transients which can occur within a system are many and varied. In general, however, the following will hold true:

1. **Lightning** - Although direct strike lightning current can potentially generate transients in the million of volts and tens of thousands of amps, electronic equipment is rarely exposed to surges of this magnitude. The greatest exposure in telecommunication systems is through inter-connecting telecommunication transmission lines. These lines can only carry voltages up to 5kV and currents of the order of 1kA. Therefore, for the vast majority of instances where the chance of lightning strike directly to the equipment is low, 5kV and 1kA is the limit of the direct strike or inductively generated surges.
2. **Power Induction** - Although power induction voltages can be quite high in voltage and current, they are often limited in duration. These voltages are caused by faults on the power system which couple into the system (usually inductively as a consequence of the surge causing a very large fault current). In virtually all modern power transmission systems, these faults are very quickly terminated by circuit breaker and re-closer equipment. This can occur in as short as a couple of cycles of power frequency voltage and rarely take longer than a second. These transients are typically modeled as a 600Vrms waveform lasting up to a second.
3. **Power cross** - Alternatively, power cross voltages are low voltage events but the exposure can occur for very long durations. They are often caused by maintenance error or cabling faults and can result in moderate currents (<25A) flowing for a long period of time (15 minutes, for example). They are predominately at mains power supply voltage levels (100-240V rms).
4. **Earth Potential Rise (EPR)** - EPR can be categorized into two forms: 1) As a result of power system faults and 2) lightning discharges. In normal industry, where fault currents from the power system are limited in magnitude by fuses and circuit breakers, power system EPR is not usually a considerable risk. EPR only becomes a significant risk when power earthing systems are significantly below standard or where high power transmission systems are used such as at power generation and distribution facilities, within high power industry, and in the vicinity of electrical traction systems (electric rail). In such circumstances, this type of surge needs to be carefully managed and expert predictions need to be made of the risk and size of events. Lightning EPR can only result due to direct strike to the building housing the equipment or in its immediate vicinity. Such events are uncommon, unless the installation is particularly vulnerable due to location or extreme height (e.g. cellular phone base-station antennae). The equipment exposure as a result of EPR can be very high, and at high earth resistance locations, may become a significant portion of the lightning current.
5. All other forms of transients tend to be lower energy forms not posing any additional risk to equipment if

protection has been suitably designed for the events detailed above.

1.2 CONVENTIONAL PROTECTION

There are two primary methods for implementing protection against surge threats, namely, blocking the surge or diverting (shunting) the surge. Nearly all conventional protection schemes used today are based on shunting architectures because of two fundamental assumptions:

- 1) Inexpensive devices which **shunt** faults of 100s of amperes and 1000s of volts exist
- 2) Inexpensive devices which **block** faults of 100s of amperes and 1000s of volts do not exist

Therefore, conventional protection relies on the primary form of protection being shunt device which divert current. However, none of the available shunt devices are sufficiently perfect to protect electronic equipment by themselves.

Electronic equipment can be damaged by voltages in the 10s of volts and currents in the 100s of milliamps if they persist for any significant length of time (more than micro-seconds). Therefore, equipment protection requires a shunt protector that: 1) can react fast enough to allow less than these values from reaching the equipment, and 2) can subsequently short circuit and protect the interface from a surge which may peak on the order of 1000A. Considering that the surge may develop in a few micro-seconds, this is quite a difficult task.

Some primary protective devices are fast enough to react in time, for example, semiconductor-based devices. However these devices tend to have limited current handling capability. Also, those semiconductor devices rated for the primary protection task tend to capacitively load a circuit (due to their physically large size) resulting in bandwidth limitations.

Non-semiconductor surge protectors, such as the Gas Discharge Tube (GDT), don't capacitively load circuits and can handle very large current (10s of kilo-amperes). However, these devices are slow to react and don't keep the voltages sufficiently low to provide successful protection by themselves.

Therefore, conventional protection must be based on a number of stages of such devices. These stages typically start with a GDT as the primary protector - for its current handling capability, followed up by a semiconductor thyristor protector for speed - the secondary protector.

1.3 COORDINATION PROTECTION

When GDT and thyristor shunt protectors are used as primary and secondary protectors, the protection coordination between them is always complicated in

practice. When a surge event occurs, the fast secondary protector will act to limit voltage within the system first (due to its speed). Often this protector will be rated to keep the circuit voltages quite low in order to protect the equipment. Thus, its action will prevent the high energy primary protector (GDT), which requires a higher voltage to operate, from working. In this circumstance, damage is inevitable to the secondary protector before the GDT operates.

This problem is solved by the complex process of inter-stage coordination. Coordination is the process of placing impedance between the primary and secondary protectors to ensure that sufficient voltage is generated across the primary protector, resulting from current flowing in the secondary protector, to trigger the primary device. Coordination is engineered properly when the primary protector operates after the secondary protector operates, yet before the secondary protector is damaged.

The coordinating impedance can be resistive, capacitive, inductive, non-linear or a combination of all of these; proper selection is critical.

Large resistance is the easiest choice to ensure that only a small current in the secondary device causes a significant voltage across the primary device causing it to operate. However, large resistance introduces considerable loss within the data transmission path which is often intolerable. Capacitance and inductance are also useful, but these impedances are frequency related and so circuits coordinated with such will work only for a band of surge frequencies. Non-linear resistance can also be used to create different coordinating arrangements based on the duration of the surge - low level surges for example which last a long time causing the coordinating impedance to change to a high resistance state choking further current flow and triggering the primary protector (the basis of operation of the PTC). A typical conventional POTS (Plain Old Telephone System) protection design with inter-stage protection is provided in **Figure 1**.

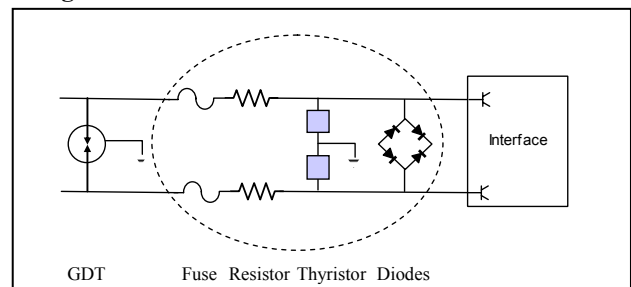


Figure 1. Conventional Protection - Circled parts indicating the secondary protection and the coordinating impedances.

In reality though, the process of selecting the best coordinating arrangement requires an in depth understanding of :

1. the surge threat;
2. the performance of all the protective components' shunting and coordinating (voltage/current/power/energy/ time) characteristics in addition to the conditions with which they trigger or not;
3. the interfaces resistibility to voltages and currents (voltage/current/time);
4. the transmission system specifications (bandwidth, maximum allowable loss)
5. the interaction between multi-stage protection circuits.

And therein is the problem. The time and frequency dependent aspects of the coordination problem make these circuits difficult to design with any degree of certainty. Consequently, testing must be used to assess the performance of a protection design within a specific system - a requirement which has founded the vast array of testing and design standards which operate within the market place. In addition, virtually all completed designs have inherent weaknesses - a weakness to sneak currents, a weakness to high energy surges, or a weakness to surges of a particular frequency or at a particular rate of repetition - and these weaknesses cause field failures, replacement cost and lack of reliability.

2 IDEAL PROTECTION

Recall that secondary protection is only required to prevent the let-through energy of the primary protector (the energy of the surge which gets past the primary protector) from damaging the load.

By definition, the peak open circuit voltage of the let-through energy past the primary protector must be smaller than that of the initiating surge – otherwise by definition, it is providing no protection at all. Therefore, a secondary protector which blocks rather than diverts this lower, manageable and largely predictable voltage would be very effective.

The requirements for this ideal blocking device are self-evident:

1. As the device needs to block the let-through energy of the primary protector, it must be a series component (in series with the transmission line), located just after the primary protector. As a series component, the device will react to the current through the device rather than voltage across the interface.
2. This series device should have a predictable, stable and low trigger current (current at which the device changes between its conductive and non-conductive state) to provide effective protection for sensitive downstream equipment.

3. It should be very fast acting (less than 10 nanoseconds) to protect equipment from surges which rise to 5kV in a micro-second - as do direct lightning strikes or lightning EPR;
4. It should be very low impedance (resistive, capacitive and inductive) so that it does not effect normal circuit operation;
5. In the blocking mode, it should be a very high impedance so that it does not dissipate significant energy during long duration surges;
6. It should be able to block voltages of the order of 1-2 kV
7. It should automatically reset after the surge to reinstate the system and continue to allow normal system operation.

In addition, for practical and economic reasons it should be small in size and be low in cost. Fultec's Transient Blocking Unit (TBU) protector meets these requirements.

3 FULTEC'S TBU

3.1 HOW THE TBU WORKS

3.1.1 General

TBU protection takes a different approach to that of conventional protection. It is still based broadly on the assumption that a primary shunt protector is needed as surge currents are more manageable than surge voltages. However, it effectively replaces the need for secondary protection and coordination considerations, with one component.

Fultec has developed the TBU to meet the requirements of the ideal protector described in Section 2. In order to understand the operation of the TBU, it is useful to picture the TBU as having a current limiting functional block and a voltage disconnect functional block.

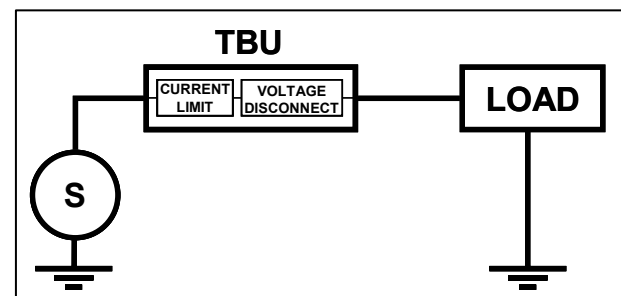


Figure 2. TBU functional block diagram

The TBU responds to both over-current and over-voltage faults as described in the following paragraphs.

3.1.2 Over-current faults

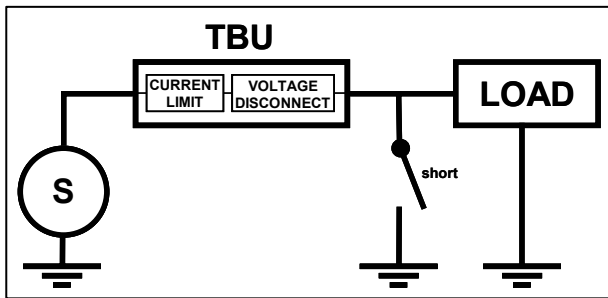


Figure 3. Over-current fault diagram

With a short circuit event occurring at time 1 (see Figure 4), the current rises to the current limiting level of I_{out} (time 2, ~10 nano-seconds). At this point, the voltage disconnect portion of the circuit operates and by time 3 (~1 micro-second), the load is disconnected from the surge. During the remainder of the surge (time 4), the TBU remains in the protected state of very low current and voltage at the load.

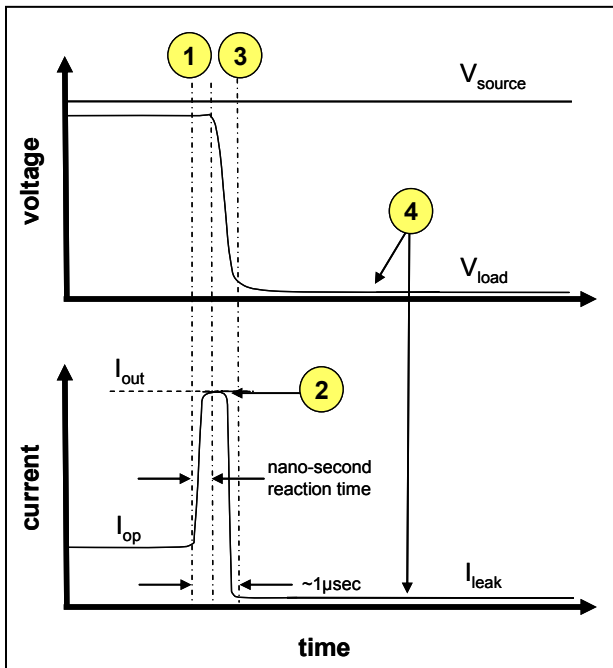


Figure 4. TBU reaction to an over-current fault

3.1.3 Over-voltage faults

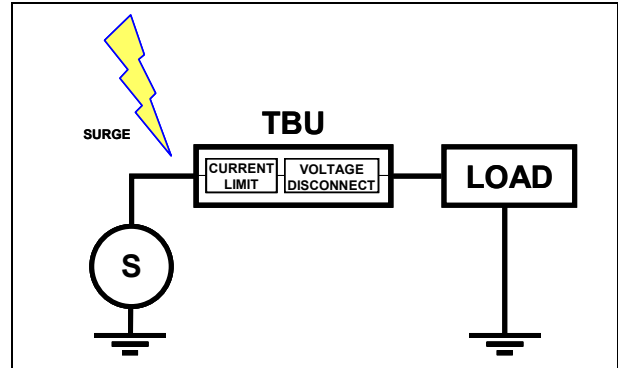


Figure 5. Over-voltage fault

With a lightning or power cross event at time 1 (see figure 6), voltage and current rise until the current limiting portion of the circuit limits current to the level of I_{out} (time 2, ~10 nano-seconds). At this point, the voltage disconnect portion of the circuit operates and by time 3 (~1 micro-second), the load is disconnected from the surge. During the remainder of the surge (time 4), the TBU remains in the protected state of very low current and voltage at the load.

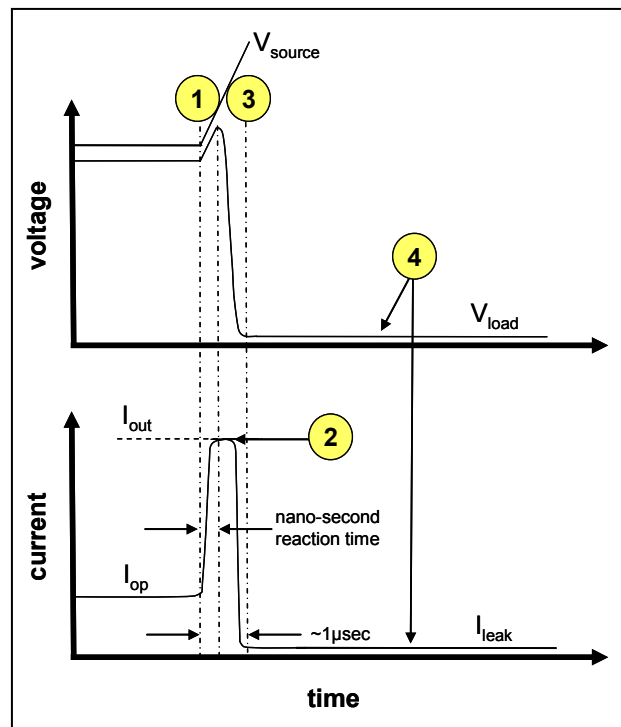


Figure 6. TBU reaction to an over-voltage fault

3.2 TBU PERFORMANCE

3.2.1 Impulsive Surge Test Results

The following test results show the TBU's response to a fast-rising lightning impulse. The test was done using a 10/1000µs impulse generator as a voltage source with the peak voltage set to 1200V. The test was conducted without shunt devices (i.e. with no GDT, thyristor or MOV).

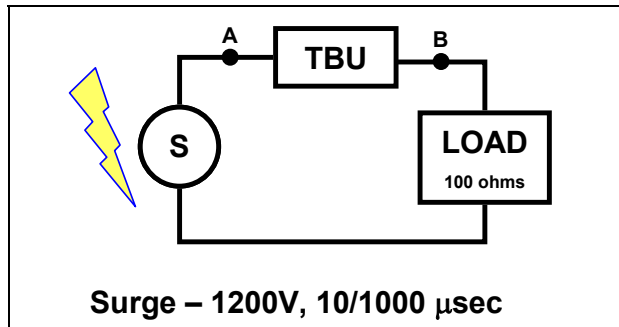


Figure 7. Lightning impulse test circuit

Figure 8 shows the input waveform on the lower trace in red (voltage on the TBU input, V_A) and the voltage at the TBU output on the upper trace in blue (V_B). The TBU current limited at ~280ma (i.e. 28V across the 100 Ω resistor) and then disconnected the load throughout the remainder of the surge. The peak voltage across the TBU was ~1200 volts, just after it triggered to protect the load. The device automatically reset after the surge ended.

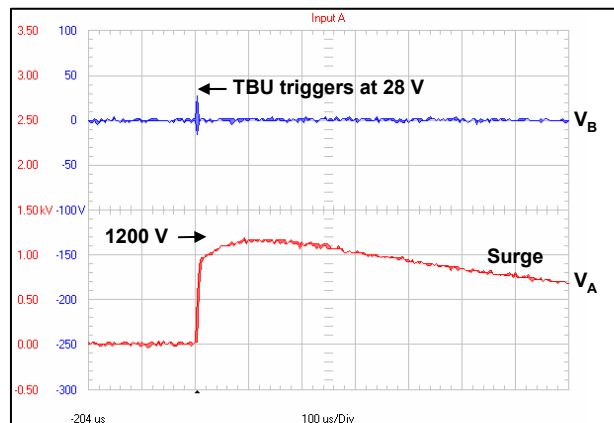


Figure 8. Impulse test of TBU device

3.2.2 AC Over-voltage

The following tests show TBU performance against an AC over-voltage.

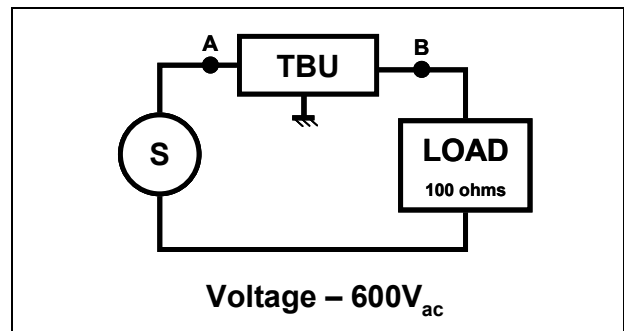


Figure 9. AC Over-voltage test circuit

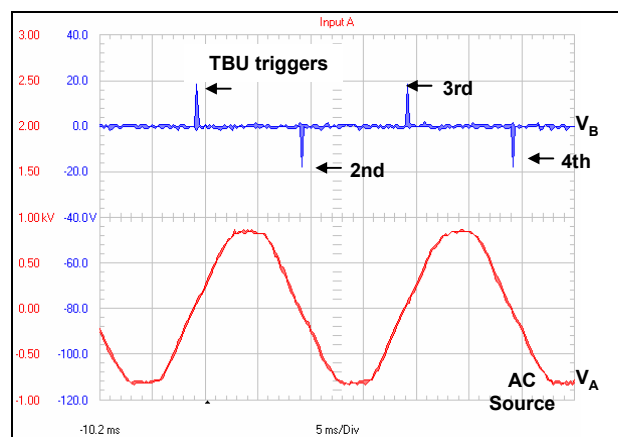


Figure 10. TBU blocking a 600Vrms power cross

At the onset of the surge, the TBU reacted to the increasing current and triggered to protect the load. The TBU remained in the protected state throughout the remainder of the high voltage cycle. At each surge zero-crossing, the TBU reset in a micro-second, and then retriggered to protect the load for each of the remaining cycles of the test. Once the fault was removed, the device reset to its normal, low impedance state.

4 SUMMARY

4.1 BLOCKING, NOT SHUNTING

In designing circuit protection, conventional wisdom has held that blocking devices that can cost effectively block real world surges do not exist. As a result, most circuit protection schemes today rely on multiple shunt devices to protect against surges. However, the currents that can occur in such surges can be significant (100's of amps) and they can last a very long time (in the order of 1 second to hours). This high current coupled with significant duration places a very large stress on all types of shunt protective devices including GDTs, MOVs & thyristors.

However, a new protection device called the Transient Blocking Unit (TBU) has proven the conventional wisdom to be out-dated. As a consequence, it is now possible to effectively block surges and prevent sensitive load electronics being subjected to high levels of energy during surge events.

4.2 CONCLUSION

The TBU provides blocking protection for both power cross and lightning. Benefits of the TBU are over-voltage & over-current protection in one device, extremely high speed performance, high blocking voltages & currents, precise output current and voltage limiting, very high bandwidth, and a small size. These advantages result in a protection device which exceeds Telcordia GR-1089 and ITU K.20/K.21 requirements, provides automatic protection coordination, and is GHz data rate compatible all within a minimum of printed circuit board area.

The TBU protector provides the circuit protection design community with a simple, superior protection device.